Shadowing and Absorption Effects on J/ψ Production in dA Collisions

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The nuclear, or A, dependence of J/ψ production is an important topic of study for nuclear collisions. It is essential that the A dependence be understood in cold nuclear matter to set a proper baseline for quarkonium suppression in AA collisions. At fixed target energies, NA50 has studied the J/ψ A dependence and attributed its behavior to J/ψ break up by nucleons in the final state, referred to as nuclear absorption. However, it is also known that the parton distributions are modified in the nucleus relative to free protons. This modification, referred to here as shadowing, is increasingly important at higher energies. We study the interplay of shadowing and absorption in deuteron-gold collisions at the Relativistic Heavy Ion Collider (RHIC) and in deuteron-lead and proton-lead collisions at the future Large Hadron Collider (LHC) [1]. We consider both spatially homogeneous (minimum bias collisions) and inhomogeneous (fixed impact parameter) results. When possible, we discuss the results in the context of data, in particular, the PHENIX data from RHIC.

At lower fixed-target energies, such as those at the CERN SPS, the x values are rather high, $x \sim 0.18$ at midrapidity, and shadowing effects are small. In this energy and rapidity regime, the A dependence of J/ψ production is typically attributed to nuclear absorption of the J/ψ. However, at energies such as those available at RHIC and the LHC, especially away from midrapidity, much smaller x values may be reached, making shadowing more important relative to absorption.

The nuclear dependence of hard process production in AB collisions is typically parameterized as

$$\sigma_{AB} = \sigma_{NN}(AB)^{\alpha} \tag{1}$$

where A and B can be either protons or nuclei and σ_{NN} is the production cross section in a nucleon-nucleon collision. It is as yet unknown if α is a strong function of energy, as predicted by some absorption models. If color singlet absorption is at work, the absorption contribution should decrease with energy because the singlet state will stay small until far outside the target. On the other hand, if the absorption cross section depends on the NJ/ψ center of mass energy, the absorption cross section should increase with $\sqrt{S_{NN}}$.

Since both initial and final-state effects such as shadowing and absorption may be dependent on $\sqrt{S_{NN}}$, empirically it would seem that α should be energy dependent. Thus absorption alone is not enough to explain the x_F dependence. Indeed, the characteristic shape of $\alpha(x_F)$ at high x_F, $x_F \geq 0.25$, also cannot be explained by shadowing alone [2]. In fact, the data demonstrate scaling with x_F, not x_2, the target momentum fraction, in contradiction to perturbative QCD factorization, indicating the possible importance of higher-twist effects.

Effects which may result in x_F rather than x_2 scaling and affect the high x_F region are energy loss in cold matter and intrinsic charm, both discussed extensively in Ref. [2]. We do not consider these effects because, at heavy ion colliders, this interesting x_F region is pushed to very far forward rapidities, outside the measureable region. Energy loss effects, such as those considered in Ref. [2], become inapplicable for $\Delta x_1 > x_1$, occurring at $x_F \leq -0.017$ at $\sqrt{S_{NN}} = 200$ GeV. We have checked the effect of energy loss in colid matter at these energies and found that the ratio dA/pp is essentially unity for $x_F > 0$. At $\sqrt{S_{NN}} = 200$ GeV and $y = 2.5$, the forward edges of the PHENIX muon arms at RHIC, $x_F \sim 0.19$ for a J/ψ with $p_T = 0$ while at $\sqrt{S_{NN}} = 5.5$ TeV and $y = 4$, the forward edge of the ALICE muon arm at the LHC, $x_F \sim 0.03$, both far from the region where intrinsic charm is important. Therefore, at collider energies, a combination of absorption and shadowing effects may be sufficient to address the J/ψ data.

We discuss the combined effects of shadowing and absorption both in minimum bias dA collisions and as a function of centrality at RHIC and the LHC. We focus on d+Au collisions at $\sqrt{S_{NN}} = 200$ GeV at RHIC and d+Pb collisions at $\sqrt{S_{NN}} = 6.2$ TeV at the LHC. While it is unclear whether pA or dA collisions will be used at the LHC, one advantage of dA is that the energy is closer to that of Pb+Pb collisions at $\sqrt{S_{NN}} = 5.5$ TeV whereas the p+Pb center of mass energy per nucleon would be 8.8 TeV. Thus the d+Pb combination has been suggested as a baseline measurement at the LHC.

The preliminary PHENIX data show that J/ψ production in d+Au collision is modified with respect to production in pp collisions at the same energy. This modification is consistent with initial-state shadowing plus final-state absorption seen at $x_F \approx 0$ in fixed-target experiments at 800 GeV [2]. More precise measurements may help to better set the level of absorption allowed by the data. Precision measurements of the centrality dependence may also help. Corresponding data from the LHC will be more useful for separating and refining shadowing models due the very low x range available for large rapidity measurements.

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